NATIONAL STEEL AND SHIPBUILDING COMPANY

LEAPFROG TECHNOLOGY TO STANDARDIZE EQUIPMENT AND SYSTEM INSTALLATION

UNIVERSITY OF NEW ORLEANS SUBCONTRACT

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SECTION NOS. 9 AND 10 — REVIEW AND APPROVAL PROCESS

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9. REVIEW AND APPROVAL PROCESS

OVERVIEW

Current shipyard standards for equipment and system installation standards are almost universally based on design standards developed for U.S. Navy Warships from the 1950's through to the 1970's. The practice in warship design has been to base the designs for new vessels on the designs developed for old vessels. As a result very little change in manufacturing or shipyard installation practices has occurred in warship design. On the other hand, there has been significant pressure to improve productivity on the commercial side of the house, in the interest of becoming globally competitive. World class shipbuilding competitiveness is based on acquiring and implementing state-of-the-art shipyard process technology, achieving high productivity in a motivated workforce within the framework of a high performance organizational structure and innovative ship design technology that will provide a technological edge of superiority over world class competition.

Techniques for the design of equipment and system installation standards are embodied in the ship design reference material for vessels that date back to the 1950's. These standards were developed to be used on vessels whose primary and secondary structures were developed based on "deterministically" developed loads for the hull girder and primary structural system members. Traditional methods for developing ship hull scantlings for the primary hull and secondary structures were based on stress loadings from still water bending moments for the primary structure and estimates for static loadings; i.e., dead and live loads on decks and flooding heads on bulkheads, for secondary structures. Deterministic approaches to characterizing the pseudo-static hull bending moment and shearing forces are found in almost every naval architecture text. The development of equipment and system installation standards has been based on the use of traditional hull loadings to satisfy strength considerations. However, it is important in the development of an innovative approach to equipment and system installation standards, to determine the effects of both strength and fatigue performance of the new standards in their attachments to hull structure.

It is very difficult for the ship design community to abandon empirically based designs that have been proven through years of successful application, especially since maritime insurers place a great deal of importance on risk avoidance. With the emphasis being placed today on efficient hull structures, the notion of cumulative damage occurring to the ships structure demands a statistical approach to the determination of ship hull primary and secondary loadings as a function of time (note: the use of high strength steel to reduce hull structural weight on dry bulk ships that is resulting in short lives for those vessels, demonstrates that vessels designed for strength alone may be susceptible to other forms of damage). As new hull designs emerge and special considerations for cost effective construction are investigated in the design process, probability based designs will provide the potential of developing a more rational approach to the determination of ship scantlings and innovative approaches to the development of equipment and system installation standards. Industry standards that are based exclusively on empirically developed designs will be obsolete as a basis for establishing standards that are both cost effective and reliable.

While is essential to consider strength when developing industry standards for equipment and system installation criteria and details, cost effective equipment and system design and hull attachment standards must necessarily address fatigue. A rational process for design innovation will include a first principles approach to engineering and testing to validate the design.

FIRST PRINCIPLES ENGINEERING AND TESTING TO SUPPORT INNOVATIVE ATTACHMENT METHODS

In an effort to employ probabilistic techniques as a basis for developing foundations for advanced combatants, a combined experimental and analytical investigation was performed by Vibtech Inc. and Lehigh University under the stewardship of Dr. Robert Dexter and with the sponsorship of the Naval Surface Warfare Center - Carderock Division, to achieve proper and cost effective foundation integration with the Advanced Double Hull (ADH), see References 1, 2 and 3. Based on these investigations, it was determined that in certain instances, foundations can be landed on deck and bulkhead plating without the use of backup structure. See *Figure 9-1*. for a conservative application of these findings. It was determined that the general specifications for ships could be revised accordingly.

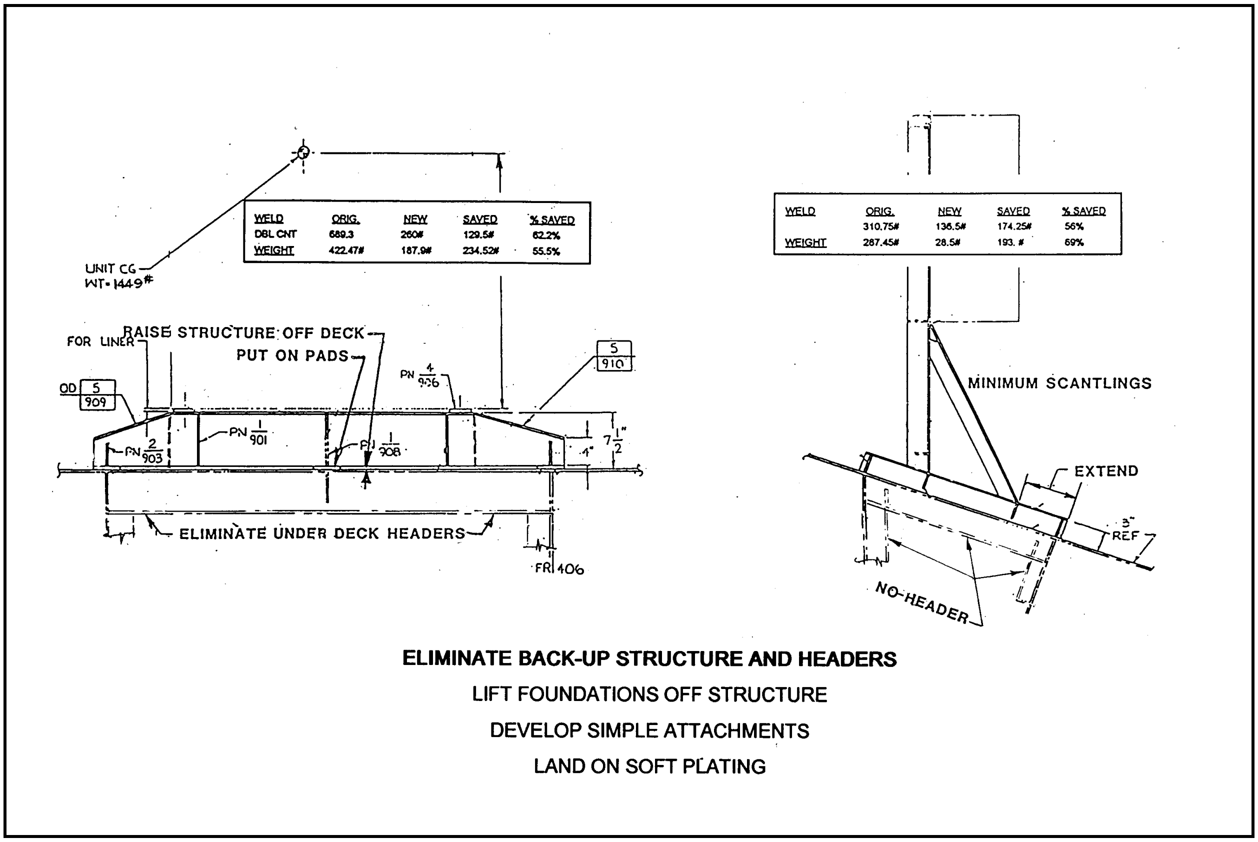

Figure 9-1 — Eliminate Back Up Structure and Headers

FIRST PRINCIPLES ENGINEERING APPROACH

The foundations investigated were based on Vibtech's family of standard designs comprised of frames, trusses and grillages and fabricated out of angle sections. This family of designs, (or Standards) described elsewhere in the report, was developed over a period of years based on a statistical compilation of foundations designs that were extracted from a number of ship design programs. See *Figure 9-1* for a characterization of the statistics for this foundation database.

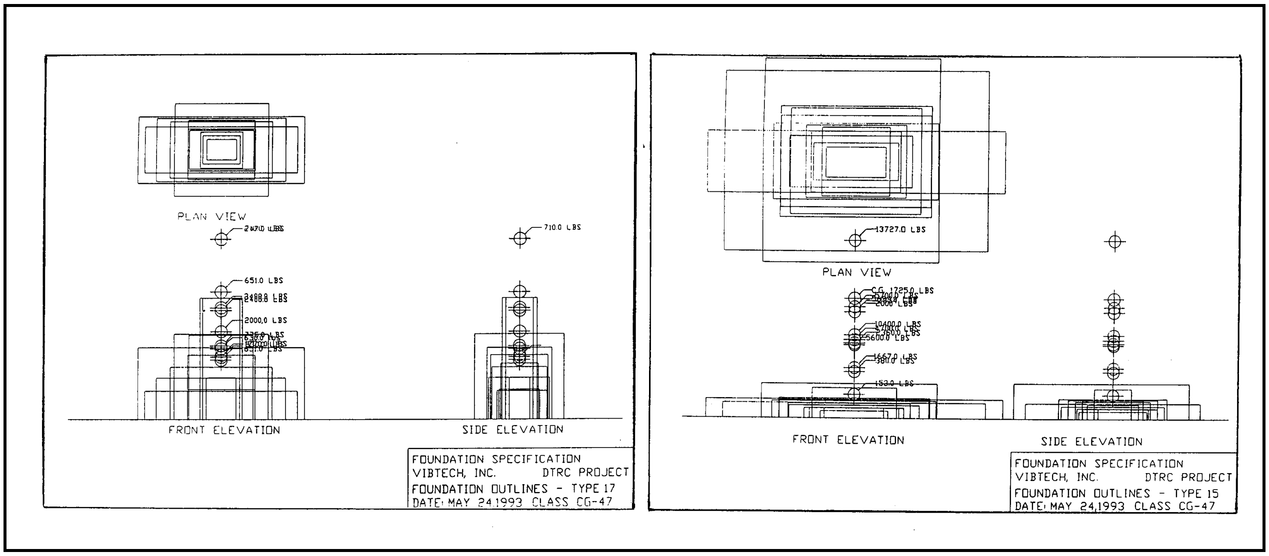

Figure 9-1 — Characterization of Foundation Database

Since ship structures are designed for both primary and significant secondary loads, there is considerable redundancy in the strength of the structure in way of most equipment and system attachments to ship structure, based on the statistics developed from previous ship design efforts. The investigations conducted under the NSWC-CD program evaluated the strength margins to see if it were possible to land on soft plate and satisfy strength, fatigue, shock and vibration requirements. Most important, for commercial ships, after strength and vibration considerations were satisfied, is to make sure that fatigue performance for the innovative attachments are satisfied. *Figure 9-2* shows that landing on unsupported plate introduces eccentricity in the attachment detail. This eccentricity causes intense local out-of plane distortion and associated stresses between the girder and the leg of the foundation attachment. Because the stress ranges, which occur locally in the eccentric details, would be much larger than the stress in the aligned details for the same loading, the resistance to cracking is significantly less for these eccentric details. However, Reference 1 and 2 point out that stress ranges from machinery and seaway loadings are very small. Therefore, satisfactory fatigue life is achievable despite the large eccentricity in the attachment detail.

During the study performed with NSWC-CD, parametric analyses were performed for over 100 candidate foundations to determine the allowable equipment mass in accord with strength, shock, vibration and fatigue performance requirements. Angle attachments were welded directly to soft plate without pads or backup structure. The tolerance for the attachment eccentricity between the deck primary structure and the attachment was up to 60 mm. Other locations were evaluated to include one thickness offset, 85 mm offset and a mid span panel location, See *Figure 9-2*.

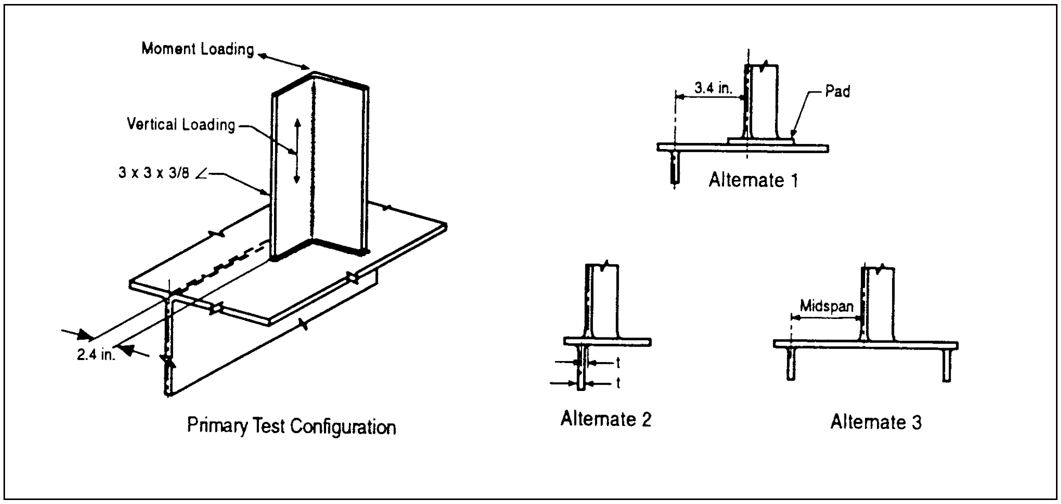

Figure 9-2 — Foundation Attachment Details

A significant part of the project was the finite element modeling of the attachment details and correlation of the calculated stresses with the static stress data. Stresses were obtained from the static test of each fatigue test specimen, at what were considered to be significant stress locations. A total of 52 standard locations were identified. The FEA models were constructed such that for the most part a node was located at these standard locations. This allowed direct comparison between stress readings from the FEA models at the nodes with the test specimen measurements. The correlation process required the data from both the specimens testing and the FEA model to be organized into a format that would permit comparison of the geometry, load case, gage locations and proper equivalent units. The results were then compared by calculating the variation between the FEA results and the average of the test results, and by plotting the various stress readings and calculations for a given geometry and loading on the same axes. The preliminary test configuration strain gage data correlated within 5% of the FEA model results. While not all configurations or locations exhibited such good correlation, the FEA results fall within the range of values obtained from the static testing. We found that we had to tailor the FEA model to the exact physical measurements of the test specimen in order to obtain good correlation. Using nominal scantling dimensions in the FEA model resulted in significant variations from the tested results. Correlation at this level of detail establishes the finite element method as a valuable design tool that supports the use of details such as those used in *Figure 9-3* and can be used to develop more innovative attachment methods.

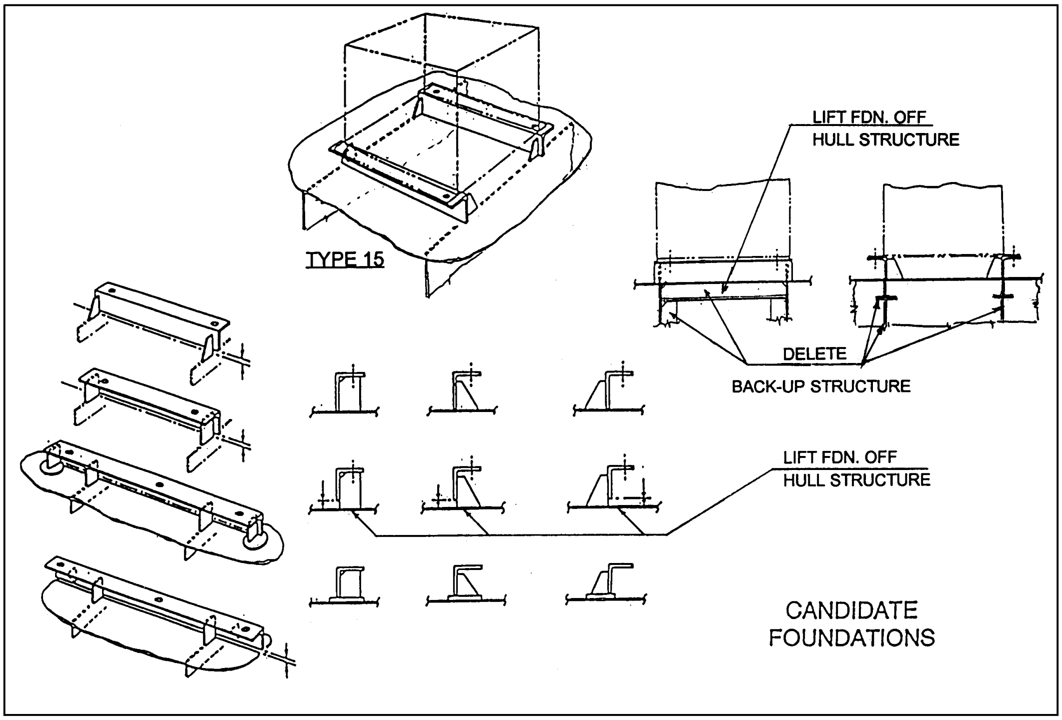

Figure 9-3 — Candidate Foundations

Reference 2 indicated that the traditional approach to ship structural design requires that the foundation attachments, i.e., the equipment and system installation attachments, land precisely over the internal girders or other primary strength members with an eccentricity of less than one plate thickness. Eliminating the need for backup structure and allowing foundations to land on unsupported plate will greatly increase productivity, save weight and reduce costs.

FATIGUE TESTING TO SUPPORT DEVELOPMENT OF INNOVATIVE ATTACHMENT DETAILS

Full scale fatigue tests were conducted to verify the fatigue performance of these eccentric attachments. Cyclic axial and bending loads were applied to angle sections which were fillet welded normal to the soft plating of the hull at various eccentricities relative to the underlying primary hull longitudinal web structure. The hot-spot stress range, See *Figure 9-1*, measured with a strain gage placed adjacent to the weld toe, was plotted with the number of cycles to through thickness cracking.

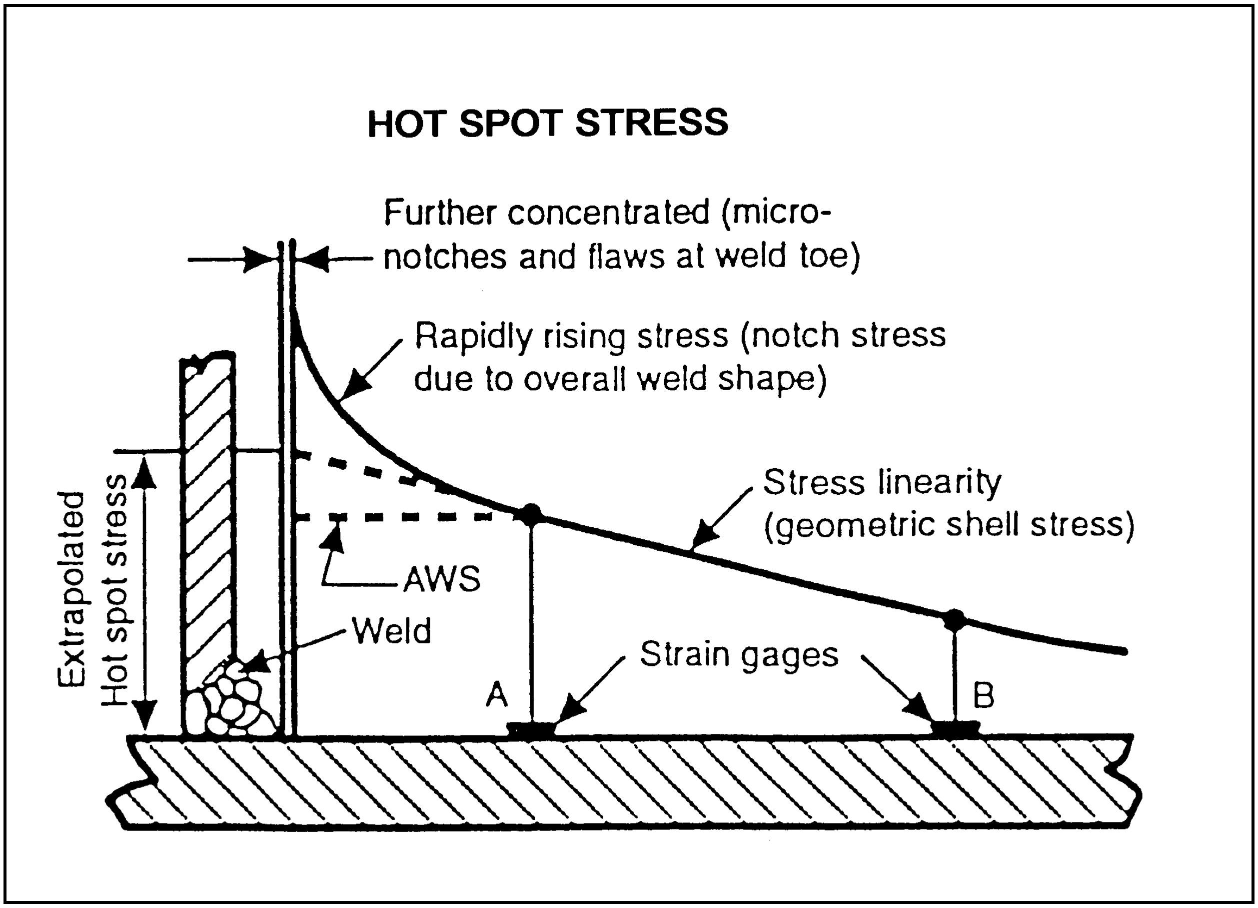

Figure 9-1 — Hot Spot Stress

The hot-spot stress, correlated reasonably well with the FEA foundation models, See *Figure 9-2*, that were tailored to take into account the attachment to the structure and the natural variability of the geometry. The "Hot-Spot" stress uses only the geometric stress in the design procedure, excluding the local stress concentration that is highly variable and difficult to quantify. The point along the weld toe at which the geometric stress is maximum is known as the "Hot-Spot". Assuming that there are no gross flaws elsewhere along the weld toe, it is expected that the cracking will start at this "Hot-Spot", See Reference 3.

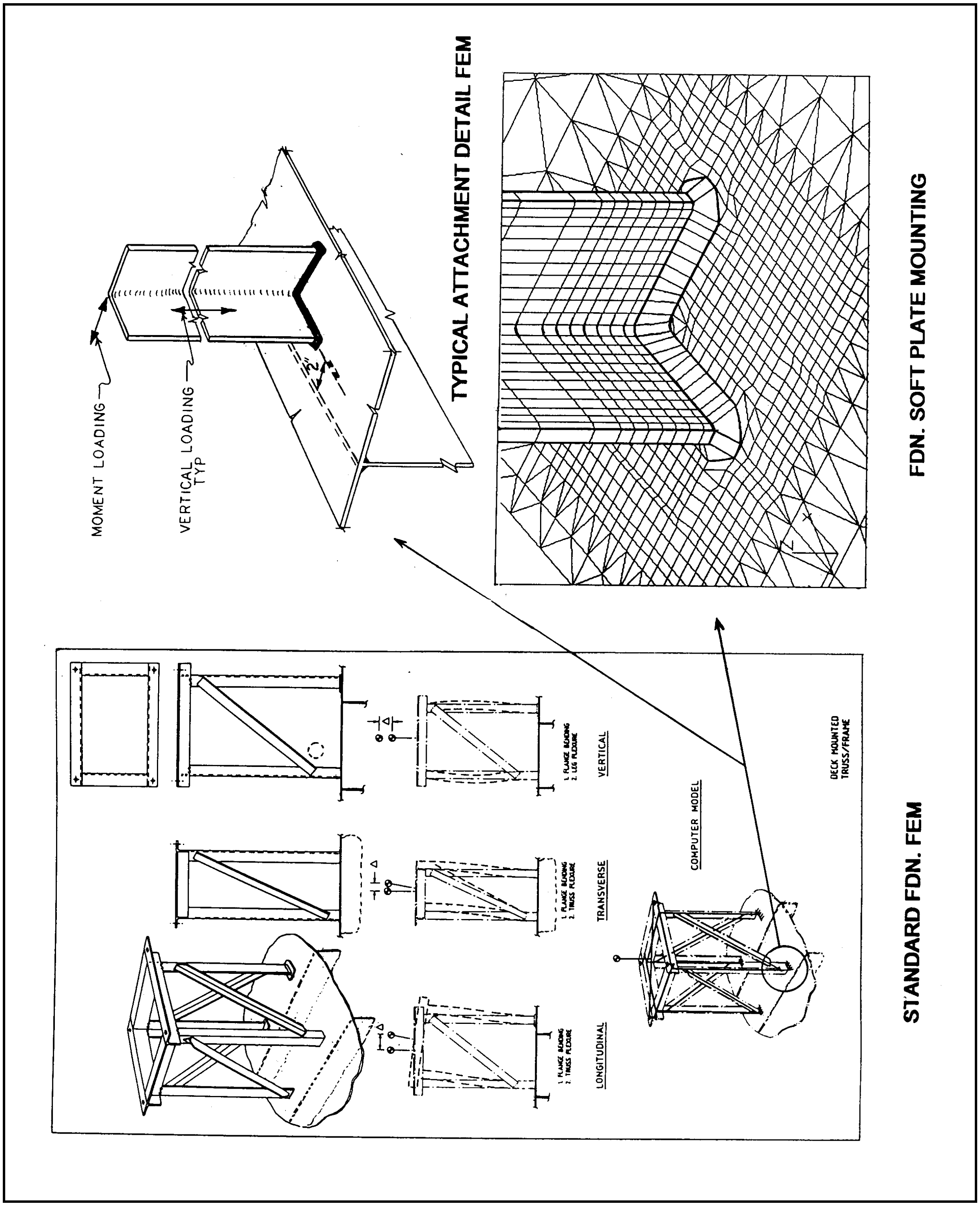

Figure 9-2 — Typical Attachment Detail FEM

Full scale tests were performed to characterize the fatigue resistance of lightweight foundation attachments with no backup structure and large eccentricity. The tests are fully described in Reference 1 and 2. Constant amplitude fatigue experiments were conducted on A572 Grade 50 angle sections (75mm x 75 mm x 10mm) with various attachment details as shown in *Figure 9-2*, Set 1 and 4. The angles were attached to 26 full scale box sections made up of 10 mm thick A572 Grade 50 steel plate. The minimum specified yield strength for A572 Grade 50 plate and angle sections is 350 MPa (51ksi). Fillet welds were made using a Carbon-Dioxide gas shielded flux-cored welding (FCAW) process.

A primary configuration was subject to three types of constant-amplitude loadings to assess its fatigue resistance. The loadings consisted of a force applied along the axis of the angle (Axial test), a force lateral to the angle (Bending test), and a simultaneous loading axial to the angle and in the plane of the top plate of the box (Biaxial test). Three "Alternate" details were tested in axial loading only to examine the influence of eccentricity to the web.

The test matrix for each configuration was a factorial design with minimum hot-spot stress and stress range as the main control variables. Tests were performed in load control using computer-controlled servo hydraulic actuators. Hot-spot strain was measured using a 3 mm gage placed 5 mm from the weld toe. Minimum stress levels were such that the details were loaded positively as well as reversed into the negative or compression region. More than sixty, (60), details were tested. Failure was defined as a through thickness crack. Crack behavior and hot-spot stresses are discussed in full in References 1,2 and 3. However, all the configurations, except alternate 2, exhibited cracking of the toe of the fillet weld attaching the angle to the plate.

In this study the AASHTO category C curve was chosen as the base-line curve or S-N curve. This curve represents the fatigue strength of a transverse weld when failure occurs for a crack at the weld toe. The "local" SCF due to the weld toe and weld discontinuities is built into the C curve. Category C is the appropriate nominal stress design S-N curve for a transverse groove weld in a plate with a uniform membrane stress. In other words the Category C curve represents a weld with a "global" stress concentration factor (SCF) of one. The hot-spot method includes the "global" SCF in the analysis. Using the ASSHTO Category C curve, a link is provided between the hot-spot approach and the nominal stress approach. The Category C curve is widely accepted in the U.S., (it is the same as the AISC or AWS Category C curve). It has a rationally determined and realistic slope and constant amplitude fatigue limit. The data from the various configurations plot in the same scatter band just above the AASHTO Category C fatigue design curve, See *Figure 9-3*. The lower bound plots directly on the Category C curve if a slope of -3 is imposed on the regression analysis. Though there is a wide range of scatter, especially in the axial data, the individual means of each set of data fall near the mean of all the data combined. Therefore, the results of the tests are assumed to be of the same population.

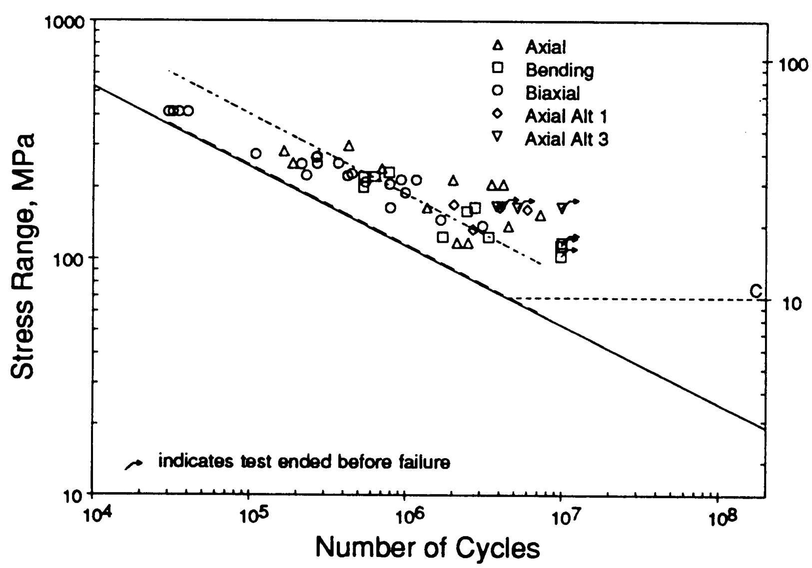

FIGURE 14 Compilation of all data plotted with respect to the AASHTO C curve (excluding Alternate 2).

Figure 9-3 — Fatigue Test Data

It is important to note that, though the S-N data for all configurations shown in *Figure 9-3* are evaluated with respect to the Category C curve, the load varies with eccentricity to attain the same stress range in each configuration. In other words, the more eccentric the detail, the less load is required to induce a given hot-spot stress. Therefore, each configuration was ranked with respect to a stress concentration factor defined as the ratio of the hot-spot stress to the nominal stress in the angle (see *Table 9-1*). If a critical hot-spot stress range governs the design, the allowable equipment mass for a given foundation will be inversely proportional to the SCF.

LOADINGS	DETAIL	SCF
AXIAL		
	PRIMARY	14.3
	ALTERNATE 1	13.2
	ALTERNATE 2	2.7
	ALTERNATE 3	23.0
BENDING		2.2
BIAXIAL		
	AXIAL STRESS	14.3
	IN-PLANE STRESS	

Table 9-1 — Stress Concentration Factors Relating Nominal Stress to Hot Spot Stress

The SCF ranges from 2,7 for eccentricities equal to the 0.38 in (10 mm) thickness of the web girder (alternate 2), to 14 at 2.4 inches (60 mm) eccentricity (Primary Detail) and then to about 23 if the attachment is located at mid-panel (Alternate 3) i.e., about 18 inches (457 mm) eccentricity. The pad in Alternate 1 distributed the stress along the plate more evenly and therefore had a lower SCF than the primary detail despite the increased eccentricity. The SCF of Alternate 2 (one thickness eccentricity) agreed well with a simple formula for a misaligned load carrying cruciform joint addressed in the American Bureau of Shipbuilding (ABS) Guide for Fatigue Assessment of Tankers.

Robert Dexter recommends that for fatigue analysis and design, the lifetime history of the stress ranges must be characterized for critical details. Consistent with most modern fatigue design recommendations, it is accepted that: 1) Miner's rule for cumulative damage is valid, and; 2) that the slope of the S-N curve is equal to 3.0 for all stress ranges. On this basis, an effective constant-amplitude stress range can be calculated which results in approximately the same fatigue damage for a given number of cycles as the same number of cycles of the variable-amplitude service history. The effective stress range is the cube root or the mean cube (RMC) of the variable stress ranges. The allowable effective RMC hot-spot stress range of 4 ksi (28 MPa) was determined by extrapolating the Category C curve to 100 million cycles, i.e., about thirty years.

The results of these fatigue tests showed that the fatigue resistance of details with varying eccentricity off the hull girder web can be assessed by using the hot-spot stress range at ¼ in. (5 mm) from the weld toe and the ASSHTO Category C design curve. The relative resistance of each configuration can be ranked using a SCF relating hot-spot and nominal stress.

CLASSIFICATION SOCIETY EVALUATION

The ABS Rules for Building and Classing Steel Vessels provides the required strength for the hull structure. The scantlings are based on the loadings and allowable stress criteria that provide designs that are generally adequate for the intended service. Typically, the rules develop the required section modulus for scantlings based on an evenly distributed design load factored into an equivalent head. Adjustments may be made for higher strength materials and even for concentrated loads such as container loadings or in some cases vehicle loadings. However, these requirements only deal with the development of the essential strength required for hull structure. The rules are appropriate for structure that exhibits good continuity, regular and well defined load paths and structural detailing that follows established "good" practice.

The ABS Rules offer no guidance for the design of structure where there are structural discontinuities or where there are concentrated cyclic loadings induced by foundations on local structure. These stresses may be concentrated on a few longitudinals or on deck or bulkhead plating rather than distributed evenly over the entire deck or bulkhead structure. The ABS rules only address strength with implicit good fatigue performance implied based on good design practice. However, ABS offers explicit guidance for fatigue design in the " Guide for the Fatigue Strength Assessment of Tankers".

Throughout their service life new ships will experience environmental loadings that will cause cyclic stress variations in structural members. Those variations can cause fatigue cracking in welded structural details if the details are inadequately designed. A fatigue assessment, supported as appropriate, by fatigue analysis and testing, should ensure that important structural members do not result in catastrophic failure. While fatigue critical locations have been identified for principle ship structural details, there is virtually no information to characterize the performance of secondary type structures such as equipment and system installation details.

The combination of concentrated loads and eccentricity of loading patterns may result in a probability for higher than normal stress patterns that may affect the fatigue life performance for such details. References 1 through 8 provide state-of-the-art information and the context within which ABS will approve special structural details. These references illustrate the fatigue performance of structural details, methods for analysis and testing of details, characterization and application of both static and dynamic loads, fatigue load characterization and proper application of "peak stress" and "hot-spot" stress analysis techniques used to assess fatigue performance.

Since foundations for equipment and system hanger attachments usually are regarded as minor structures, ABS has not been traditionally involved in assessment and approval of these type of structures, other than main machinery foundations that may form part of the principle hull structure. However, since part of the innovative methods considered for "Leapfrog Technologies to Standardize Equipment and System Installations" is to land lightweight equipment foundations and distributive system hangers on soft plating to simplify construction and reduce cost, it is considered appropriate to evaluate the fatigue performance of such details with appropriate techniques. We believe that substantial work has been performed to validate such an approach as provided in References 1, 2 and 3. Never the less, it is considered prudent to involve the regulatory agencies in such evaluations in order to achieve a consensus in support of such cost saving approaches.

The American Bureau of Shipping was asked to comment on the results of the FEA and Fatigue Testing study of hull equipment foundation attachments. Their positive comments are attached herewith in Appendix ? While ABS comments are qualitative and appear supportive of the general approach advocated herein. It will be incumbent on shipbuilders to evaluate new developments for equipment and system attachments on an individual basis in order to provide assurance that the approaches used will maintain proper hull integrity

Fatigue design procedures using a characterization of stress in way of structural details have been developed as a basis for fatigue analysis. Munse, Stambaugh, Park, Lawrence and Bea describe fatigue stresses in ship details as a consequence of probabilistic based design hull girder loading and resulting stresses, See References 4 through 8. Their methods take into account the overall configuration of the detail without modeling the explicit geometry of the weld detail. They have developed special S-N curves that define the permissible stress range (double amplitude) for use with their particular description of the detail.

ABS Comments On Foundation Analysis and Testing Program at Vibtech Inc. and Lehigh University sponsored by the Naval Surface Warfare Center – Carderock Division:

See the following letters:

Comments on Paper "Foundations for Advanced Double Hull Combatants", by J. Hopkinson, R.J. Dexter, and D. McAfee

Conunents by Y.K. Chen, ABS

9/11/98

The paper presents an extensive study, in both FEA and experiments, on the cost-effective design of lightweight foundations on the unidirectional double hull combatants with the consideration of shock, vibration, fatigue and ultimate strength. Some of my specific comments on the paper are given below:

I . It is interesting to note that as concluded by the study, foundation angles of lightweight equipment in most cases can be fillet welded directly to the inner bottom plating without pads or backup structure or aligning with bottom girders. Although the offsets of foundation legs from girder webs would significantly increase the stress concentrations at the weld toes, and decrease the fundamental natural frequency of the system, the study showed that the attachment details met the performance

requirements for most equipment weights with associated foundation types from the point of view of shock, vibration, fatigue and static strength. This is very useful for cost-effective design and installation of lightweight foundations on inner bottoms of the double hull ships.

2. Vibration is an important aspect of the foundation design. Because of the so-called "soft mounting" as a result of increasing offsets of leg attachment points from bottom girders, the fundamental natural frequency of the foundation system will definitely decrease, possibly lower than the 15 Hz called for by the CG-47 Specifications for avoiding possible resonance with propeller excitation. By simply increase the stiffness of the foundation structure, as suggested by the paper, may not be able to raise the frequency high enough to meet the requirements. However, this point may be easily proved by a further study in this regard using the simple frame models as shown in Figure 4, with varying stiffness for the boundary elements and the foundation structure.

3 For fatigue strength assessment of the leg attachments, it is true that the so-called "nominal stress approach" is difficult to apply in this case, and the "hot spot stress approach" is more appropriate. However, the discussions on E-curve for the nominal stress approach, C-curve for the hot spot approach and the expression of the high magnitude SCF (in the range of 13 to 23) may be misleading. Actually, the corresponding nominal stress for the measured hot spot stress (or calculated by FEA) near the weld toe on the inner bottom is the plating local bending stress (without the presence of the attachment) caused by local deformation due to leg loads, not the axial or bending stress in the leg. When using the leg axial or bending stress as the nominal stress, the SCF should really be compared to the hot spot stress at the upper weld toe on the leg itself. This is also the reason that the SCF found in bending is so much lower than the SCF in axial load, contrary to the well fact that SCF in bending is higher that SCF in axial load. However, the present expression of SCF is still a good measure of the hot spot stress at the lower weld toe on the attached plating caused by the axial stress in the leg, only that the ratio should not be considered as SCF to the leg axial stress. If the nominal stress approach needs to be used in this case for fatigue assessment, the nominal stress should be taken as the local bending stress on the inner bottom plating.

4. The so-called "hot spot stress" is determined by taking into account the stress concentration due to structural discontinuities and presence of attachments, but excluding the effects of welds. As a result, there is no difference for

the SCF so determined for the case with fillet welds and the case with full penetration welds. When using the hot spot stress approach in the fatigue assessment of the attachment details, the C-curve as used in the study would be used in both cases. What is the authors' opinion in dealing the two cases which are expected to have significantly different fatigue performance?

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8 May 1995

AAM/ls P-11

Mr. John Hopkinson, President
Vibtech, Inc.
125 Steamboat Ave.,
Box 435
North Kingstown, RI 02852

Subject: ABS Comments to "Foundations for Advanced Double Hull Combatants" Dear Mr. Hopkinson:

We have your telefax of 27 February, 1995 submitting one (1) copy of the following technical paper:

Foundations for Advanced Double Hull Combatants

and requesting our comments. We have reviewed the work and find it to be a comprehensive study dealing with a neglected shipbuilding topic, equipment foundation design, and showing potential for the reduction of both time and cost when fabricating a vessel.

The basic theme of the paper is that, for certain lightweight prices of equipment, their supporting foundations can be landed directly on the cell structure of unidirectional, double hull vessels without the typical concerns of alignment with the main framing or providing supplemental back-up structure. We must advise that many of the equipment foundations which fit into this category would not, in themselves, be class items. However, the Bureau is generally interested in the foundation's attachment to the basic hull structure since the type of attachment proposed in your paper would typically be considered to be a "hard spot" where cracking of the structure could initiate.

We have considered the methodology used in the paper, that is, the use of finite element models (FEM) to analyze the equipment foundations and their attachments to the cellular ship's structure followed by full-scale or half-scale fatigue testing of the foundation to validate the results of the FEM to be both acceptable and commendable. It is not often that we see analytical studies verified and calibrated by physical testing.

The modes of failure checked in the analysis appear to verify that the foundations and the attachment to the cellular hull structure would be acceptable for strength, vibrations, fatigue, deflection, hull deflection induced loads, loads induced due to restraint by attached systems (e.g. piping), ship motions and slamming. The only loading which does not seem to have been considered is the case of an equipment foundation attached to a tank boundary and restrained by piping systems. When the tank is filled to the overflow or experiences internal pressure, the hydrostatic head pushes the tank boundary plate into foundation's attachment point - a classic "hard spot."

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Vibtech, lnc.
8 May 1995
Page 2

For practical application, we presume that some form of tabular breaking down of foundation types into grillages, frames and truss would have to be developed showing the permissible mass of equipment vs. the eccentricity of attachment of the foundation from the hull cellular structure. Also, the thickness of deck plating on which the foundation is mounted would have to be included. There could be some plate thicknesses where additional consideration is required.

We do not believe that foundations for *massive, vital or alignment sensitive* equipment should be landed on ship's structures without regard to the location of back-up support structure. Also, equipment foundations which are located such that they cannot be readily visually inspected and those which would require an extraordinary amount of system disassembly work to repair any problems should not use this method of attachment.

The potential owners of vessels should be made aware of the fact that lightweight equipment aboard their ships is being installed on foundations without back-up structure. They may be an objection to using this installation method aboard their vessels.

Your foundations study was undertaken for possible use aboard advanced double hull combatant vessels. However, it appears that the study could also be applied to conventionally framed cargo vessels.

An interesting additional finding in your analysis was the unexpected deflection behavior of the finite element model of the unidirectional double hull machinery space. This finding was passed along to our Advanced Analysis Group who have done their own analysis of a proposed new construction tanker which uses the unidirectional double hull framing system. They generally agree with your results.

We appreciate the opportunity to read and comment on your paper.

Very truly yours,

AMERICAN BUREAU OF SHIPPING Christopher J. Wiernicki, P.E.
Vice President of Engineering
Manager, Ship Engineering Department

References:

1. Hopkinson, John J. and Dexter, Robert J. ‘et al’, Final Report for N00167-02-K-0042, “Producibility: Foundation Integration with Double Hull”, ATLSS Report No. FFP 93-10, Sept, 1993, Distribution Limited to U.S. Government Agencies Only

2. Hopkinson John J., Dexter Robert J. and McAfee, David, “Foundations for Advanced Double Hull Combatants”, The Advanced (unidirectional) Double-Hull Technical Symposium, Gaithersburg, MD., October 25-26, 1994

3. Dexter, R.J., Tarquinio, J.E., and Fisher, J.W., Application of Hot-Spot Stress Fatigue Analysis to Attachments on Flexible Plate, 13th International Conference on Offshore Mechanics and Arctic Engineering, Houston, TX. February 1994

4. Munse, W.H., Wilbur, T.W., Tellurian, M.W., Nicoll, K. and Wilson, K., “Fatigue Characterization of Fabricated Ship Details for Design”, SSC-318, 1983

5. Stambaugh, K.A., Van Mater, Jr., P. R.. and Munse, W.H., “ Fatigue Performance under Multi-axial Loading in Marine Structures”, SR-1323 Final Report, dated June 1989

6. Park, K.K. and Lawrence, F.V., “Fatigue Characterization of Fabricated Ship Details for Design - Phase II”, SSC-356, June 1989

7. Stambaugh, K.A., Leeson, P.H., Lawrence, F., Hou, C.Y., Banas, G., “Reduction of S-N Curves for Ship Structure Details”, SR-1336, Final Report, Sept 30, 1992

8. Stambaugh, K.A., Lawrence, F., “ Improved Ship Hull Details Relative to Fatigue”, Sept 30, 1992